A TEST OF THE FELDSPAR METHOD FOR THE DETERMINATION OF THE ORIGIN OF METAMORPHIC ROCKS

CHARLES GORDON CARLSON
The University of Wisconsin

1. *Purpose of paper.*—That feldspars may serve as indicators of the original character of gneisses and schists is dependent upon the narrow range of composition possessed by the plagioclase feldspars of igneous rocks. Thus more than one kind of plagioclase feldspar is rarely found in an igneous rock except in certain zonal intergrowths or in some porphyries where the feldspars forming the phenocrysts may be of slightly different composition from those of the groundmass.

In sediments, except in rare cases where they are derived from rocks having feldspars with a narrow range of composition, the limited feldspar composition found in igneous rocks is not to be expected. Usually sediments are derived from many sources and consequently mixtures of all kinds of feldspars are possible. It would seem reasonable then to believe that gneisses and schists with a narrow range of feldspar composition are probably igneous in origin, whereas metamorphic rocks with several varieties of feldspar are very likely of sedimentary origin. This belief, however, rests on the fundamental assumption that the feldspar range typical of sediments does not radically change during anamorphism of these sediments. It is readily seen that if such a change does take place it vitiates any conclusions which might be reached. Similarly, if in the anamorphism of igneous rocks a radical change in the original feldspar composition results, this also would militate against the efficacy of the feldspar method.

That feldspars undergo alteration in various stages of the metamorphic cycle is generally recognized. It is not known that this

alteration tends to produce feldspars of varied composition from one particular feldspar, nor conversely to change a wide feldspar range into a narrow one.

The purpose of the work of this thesis was to determine the efficacy and validity of the hypothesis as above stated, namely, that metamorphic rocks having a narrow range of feldspar composition are probably igneous in origin, whereas those having a wide range of feldspar composition are more likely of sedimentary origin. To test the validity of this hypothesis it was first necessary to get some idea as to the abundance of feldspars in various sediments and also to determine the range in composition of these feldspars. This involved a study of sediments both in the unconsolidated and consolidated form. It was then further necessary to study metamorphic rocks of known sedimentary and igneous origin in order to note whether the feldspar composition was such as would have characterized the original sedimentary or igneous equivalent. The methods used in this study and the results obtained are presented in this paper.

The writer wishes to acknowledge his indebtedness to Dr. Edward Steidtmann, of the University of Wisconsin, for suggesting the fundamental idea upon which the feldspar method is based, and to Professors A. N. Winchell and C. K. Leith for suggestions and criticisms.

2. *Methods used to determine feldspars.*—In the determination of the feldspars two distinct methods were used depending upon the character of the material to be examined. Where thin sections were available and the rock was fairly coarse grained the Fouque method was found very serviceable.

When thin sections were not available and the material was so fine grained as not to be adapted to the Fouque method, the material was studied in powdered form and the feldspars determined by immersion in a series of liquids of known index. With the liquids either the Becke or inclined illumination method can be used. The determination of feldspars from rock powders in this manner is especially valuable in cases where the feldspars are partly altered, where the rock is fine grained, when the feldspar content is low, and for all unconsolidated sediments.

3. *The materials studied.*—In getting material together for study the attempt was made to make this selection one which would most thoroughly test the feldspar method. The mineralogic composition of unconsolidated and consolidated sediments as well as of metamorphic rocks of known origin was therefore determined. In order that the sediments might represent the breaking down of as many rock formations as possible, they were chosen so as to include a wide geographic and stratigraphic distribution. The aim was also to avoid limiting the material studied to any one particular realm of deposition. Beach sands as well as sands of glacial, eolion, and locustrine origin were therefore chosen. The consolidated sediments examined included arkoses, graywackes, tuffaceous sandstones, and shales. Since the purpose of studying the metamorphic rocks was to determine whether anamorphism causes any changes in the feldspar composition of the original rock, the gneiss and schists were selected which showed different kinds and degrees of change.

4. *Tabulation of results.*—The table on page 636 shows the results of the feldspar determinations for the various kinds of material studied.

5. *The relative abundance of feldspars in sediments.*—The data available are not sufficient to warrant a dogmatic statement as to whether certain feldspars are more abundant in sediments than others. The studies by the writer of a large number of sediments of different origin, as well as of wide geographic and stratigraphic distribution, suggest very strongly, however, that certain feldspars are very common in sediments, whereas others are quite rare. Orthoclase, microcline, and the acid plagioclases are much more frequently met with in sediments than the basic feldspars. Microcline seems to be more common than any of the others, so that a careful study of sands which appear to be entirely composed of quartz usually reveals a few grains of this feldspar. By referring to the accompanying diagram (Fig. 1) the relative abundance of the various plagioclase feldspars is strikingly brought out. This abundance of the feldspars mentioned indicates either that they are especially common in the rocks from which they were derived or that the basic plagioclases suffer much more rapid

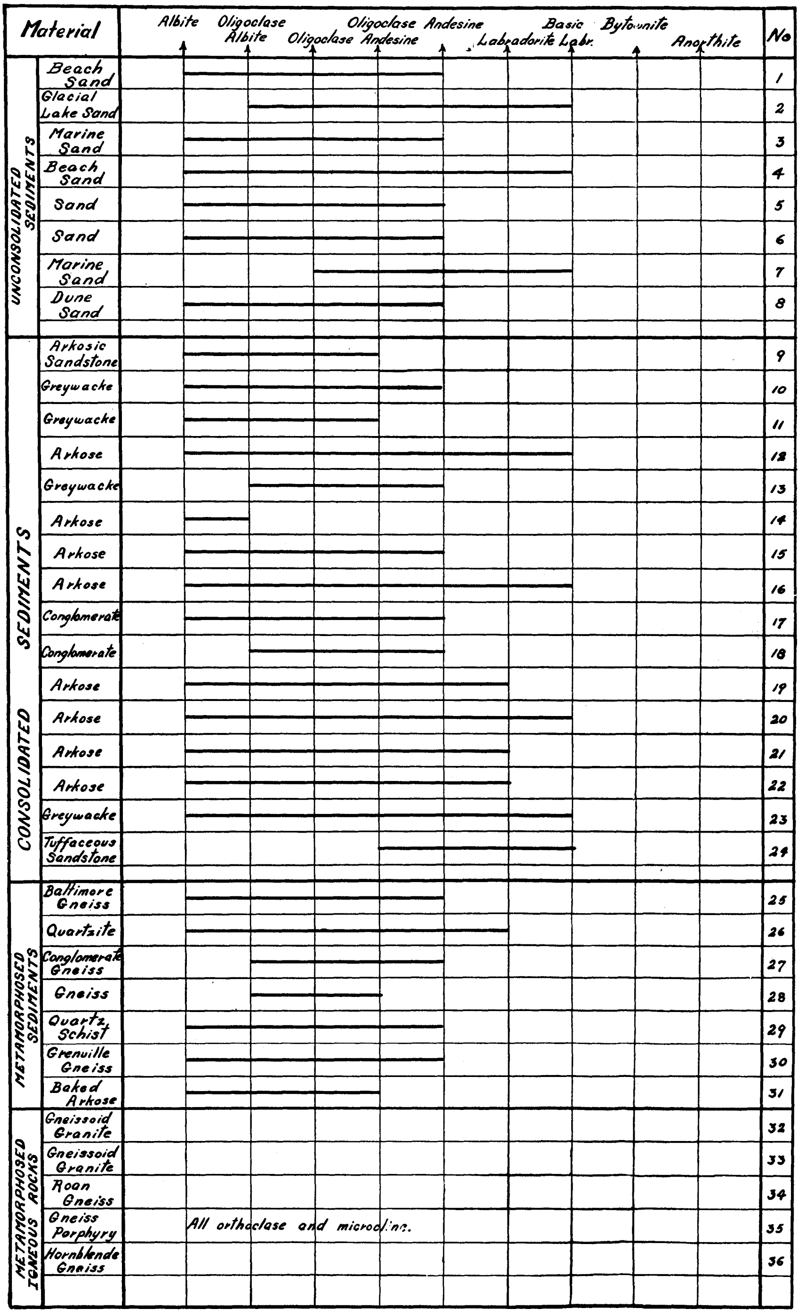

FIG. 1.—Diagram showing the range in feldspar composition for the various materials studied. The numbers refer to those on the accompanying tables where additional data are given. The solid black lines opposite the material indicated in the left-hand column show the range in feldspar composition for that material. Note the wide range of feldspars in the material of sedimentary origin as compared to that which is igneous in origin.

TABLE SHOWING DATA OBTAINED AS TO FELDSPAR COMPOSITION OF SEDIMENTS AND METAMORPHIC ROCKS OF KNOWN ORIGIN

	No.	Material	Locality	Feldspars Found	Method Used*	Remarks
Unconsolidated Sediments	1......	Quartz Beach sand	South Carolina, Sullivans Island	Albite oligoclase, andesine, microcline, and orthoclase	B	Feldspar forms about 5 per cent of sand
	2......	Glacial Lake sand	Middleton, Wisconsin	Oligoclase albite, oligoclase, andesine, labradorite, basic labradorite microcline	B	....
	3......	Marine sand Cambrian	South Point, Wisconsin	Albite, oligoclase, andesine, orthoclase, and microcline	B	Mineralogical composition of this sand = 36 per cent carbonate, 45 per cent quartz, 14 per cent feldspar, 5 per cent augite, hypersthene, apatite, zircon, garnet
	4......	Beach sand. Largely derived from limestone but containing some glacial sand	Anticosti Island	Albite, oligoclase, andesine, basic labradorite, orthoclase, microcline	B	Mineralogical composition of this sand = 85 per cent carbonate, 8 per cent shale particles, 7 per cent quartz, feldspar and heavy residuals
	5......	Sand. Contains reworked glacial material	From mouth of estuary between Goose and Lacroix Points, Anticosti Island	Albite, oligoclase, andesine, microcline, and orthoclase	B	Mineral composition—52 per cent c arbonate, 43 per cent quartz, and feldspar, 5 per cent heavy residuals. Bulk of sand of .124 mm. size
	6......	Sand. Largely derived from limestone	From work in Chicotte formation Anticosti Island	Albite, andesine, microcline	B	Mineral composition = powder. 94 per cent carbonate, 4 per cent quartz, and feldspar; 2 per cent rock and mineral particles, 83 per cent of material coarser than .417 mm.

Consolidated Sediments	7......	Marine sand Cambrian	Middleton, Wisconsin Interstratified with Oneota dolomite	Oligoclase, andesine, labradorite, basic labradorite, orthoclase and microcline	B	Mineral composition: 60 per cent quartz, 27.4 per cent carbonate, 11 per cent feldspar, 1.6 heavy residuals. Microcline abundant
	8......	Dune sand	Golden Gate Park, California	Albite, oligoclase, andesine, microcline and orthoclase	B	....
	9......	Arkosic sandstone	Wausau, Wisconsin	Albite, oligoclase, oligoclase andesine, orthoclase and microcline	F	Plagioclase feldspars abundant. Pre-Cambrian
	10......	Graywacke	Wausau, Wisconsin	Albite, oligoclase albite andesine, orthoclase	F	Pre-Cambrian
	11......	Graywacke	Wausau, Wisconsin	Albite, oligoclase, andesine oligoclase, orthoclase	F	Pre-Cambrian
	12......	Arkose Jurassic Triassic	New Jersey	Albite, oligoclase, albite, andesine, basic labradorite, microcline	B	Rock is from the Newark series; interpreted as being of terrestrial origin
	13......	Graywacke Huronian	Hurley, Wisconsin	Oligoclase albite, oligoclase, oligoclase andesine, orthoclase and microcline	F	Rock composed of quartz and feldspar chiefly. Rock particles also present
	14......	Arkose (Brown sandstone)	Hummelstown, Pennsylvania	Albite, oligoclase albite, orthoclase and microcline	F	Rock is part of Newark Series, of Jurassic-Triassicage
	15......	Arkose	Clinton Point, Wisconsin	Albite, oligoclase, albite, oligoclase andesine	F	Feldspar is considerably kaolinized

* The letters B and F under the column headed "Method Used" stand for Becke and Fouque.

TABLE SHOWING DATA OBTAINED AS TO FELDSPAR COMPOSITION OF SEDIMENTS AND METAMORPHIC ROCKS OF KNOWN ORIGIN—*continued*

	No.	Material	Locality	Feldspars Found	Method Used*	Remarks
Consolidated Sediments	16......	Arkose	Whitehall, Montana	Albite, oligoclase albite, oligoclase, andesine, basic labradorite, orthoclase	F	Plagioclase is abundant. Rock is fine-grained conglomerate
	17......	Conglomerate Huronian	Cobalt, Ontario	Albite, andesine, microcline and orthoclase	F	Plagioclase not abundant
	18......	Conglomerate	Oconto Bay, Wisconsin	Oligoclase albite, andesine, orthoclase and microcline	F	Plagioclase not abundant
	19......	Arkosic sandstone Keweenawan age	Ontonogan County, northern Michigan	Albite, andesine, labradorite, microcline and orthoclase	B	Labradorite least abundant of plagioclases
	20......	Arkose	Devils Rock, Cobalt District, Ontario	Albite, oligoclase, andesine, basic labradorite, orthoclase and microcline	B	Orthoclase abundant. Huronian
	21......	Mashed arkose	Portage, Minnesota	Albite, oligoclase, andesine, labradorite, orthoclase and microcline	B	Microcline abundant; some of feldspars partially recrystallized. Huronian
	22......	Arkosic sandstone	Southeast of Houghton, Michigan	Albite, andesine, labradorite, microcline	B	Cambrian
	23......	Graywacke	Grafton Center, New Hampshire	Albite, oligoclase, andesine, basic labradorite	B	....

Metamorphic Sedimentary Rocks	24......	Tuffaceous sandstone	Teslo, California	Oligoclase, andesine, labradorite	B	......
	25......	Baltimore gneiss	Baltimore, Maryland	Albite, andesine	B	......
	26......	Arkosic quartzite	Temiskaming, Ontario	Albite, andesine, labradorite, microcline, orthoclase	B	Huronian age
	27......	Conglomerate gneiss	Mill River, Massachusetts	Oligoclase, albite andesine, orthoclase, microcline	B	Microcline abundant
	28......	Gneiss	Tyringham, Massachusetts	Oligoclase albite, oligoclase andesine, microcline and orthoclase	F	Microcline abundant
	29......	Quartz schist	Ramshorn District, Montana	Albite, oligoclase, andessine, orthoclase	F	......
	30......	Grenville gneiss	Near New York City	Albite, oligoclase, andesine	B	......
	31......	Baked arkose conglomerate	South Britain Connecticut	Albite, oligoclase, andesine	B	......
Metamorphic Igneous Rocks	32......	Gneissoid granite	Three Rivers, Massachusetts	Albite only	B	......
	33......	Gneissoid granite	Thomaston, Connecticut	Albite only	B	......
	34......	Roan gneiss	Northern Georgia	All andesine	B	......
	35......	Gneiss porphyry	Dame de Muse, Ardenned, Belgium	All above albite. Microcline and orthoclase abundant	B	......
	36......	Hornblende gneiss	Ilchester, Maryland	All andesine	B	......

* The letters B and F under the column headed "Method Used" stand for Becke and Fouque.

decomposition. The latter seems the more reasonable conclusion since many of the sediments studied have had their origin in areas of basic igneous rocks. At Keweenaw Point for example the Keweenawan sediments show a very small amount of the basic feldspars as compared to the acid varieties and yet the sediments have been largely derived from rocks of a decidedly basic character and from rocks in which basic feldspars are known to be very common. It is also generally recognized that the calcic feldspars are more readily decomposed than the more alkaline varieties. Iddings states that

> The alkalcic feldspars are not attacked by hydrochloric acid. The more calcic feldspars are decomposed by the acid in proportion to their content of calcium. Thus oligoclase and andesine are not attacked, labradorite is slightly acted upon, bytownite and anorthite are decomposed with the separation of gelatinous silica. In the rocks the more calcic feldspars are more readily decomposed than the more alkalcic feldspars in general.[1]

Feldspars are much more common in sediments than has generally been supposed. A large number of "sandstones" and "quartz" sands were in many cases found to have a considerable percentage of feldspar. Sands with a 5 per cent content of feldspar are not at all uncommon, while certain glacial and marine beach sands may contain feldspar up to 25 per cent.

6. *Feldspar range of rocks studied.*—It was desired to determine, by the work pursued in connection with this thesis, just what range in feldspar composition can be expected in sediments, and further to ascertain whether, during anamorphism, there is any change in the feldspar composition of the original igneous or sedimentary equivalent. The results obtained show that almost any combination of the various feldspars can be found in sedimentary rocks. Of the twenty-four samples studied, these samples including unconsolidated and consolidated sediments, twenty-three showed a range in feldspar composition from albite to andesine. Labradorite was found in eleven of the samples, while anorthite, due undoubtedly largely to its ready solubility as well as comparative rarity was not noted in any of the samples studied. As was expected glacial and marine beach sands show a very large range

[1] J. P. Iddings, *Rock Minerals*, p. 204.

in feldspar composition. Studies of metamorphic rocks of known igneous and sedimentary origin showed that the former retained their limited feldspar composition, whereas the metamorphic-sedimentary rocks included feldspar combinations such as would characterize the original sedimentary rock. The conclusion, as based upon the work done, is that there is no decided change, during anamorphism, of the feldspar composition possessed by the original unmetamorphosed material.

7. *The usefulness of the feldspar method as compared with the present criteria used in the determination of the origin of metamorphic rocks.*—The present criteria which are used to determine the igneous or sedimentary origin of metamorphic rocks are dependent upon field relations, together with chemical and mineralogical composition. Field evidence consists chiefly in tracing metamorphic rocks into the less altered igneous or sedimentary equivalents. Thus a basalt has often been observed to grade into a chlorite or micaceous schist. Similarly banded gneisses are often associated with and grade into granites. Chemical evidence suggestive of a sedimentary origin consists, according to Bastin[1] "of a dominance of magnesia over lime, potash over soda, excess of alumina and high silica. If the chemical composition is essentially that of an igneous rock this fact favors igneous origin." Mineralogical evidence favoring a sedimentary origin consists of a high content of quartz as does also an abundant development of aluminum silicate minerals. The presence of graphite probably denotes a sedimentary rather than an igneous origin.[2] Rounded grains of such minerals as garnet, sphene, and especially zircon have been taken as evidence of sedimentary origin. These minerals are especially resistant to weathering and will remain after the other minerals have been completely altered.

The plagioclase feldspar method is an addition to our mineralogical criteria. The results obtained prove the feldspar method to be a valid and reliable method for the determination of the

[1] Edson S. Bastin, "Chemical Composition as a Criterion in Identifying Metamorphosed Sediments," *Jour. Geol.*, XVII (1909), p. 472.

[2] J. D. Trueman, "The Value of Certain Criteria for the Determination of the Origin of the Foliated Crystalline Rocks," *Jour. Geol.*, XX (1912), pp. 228–58, 300–15.

metamorphic rocks to which it is applicable, and this means any rock containing recognizable feldspar constituents. The studies show that metamorphic rocks in general, except where they have suffered alteration due to ordinary weathering or hydrothermal alteration, contain such constituents. Where hydrothermal alteration has been effective, as in the proximity of the intrusive porphyries of the west, some other criteria must generally be resorted to. Even here, however, the alteration is not likely to have proceeded far from the main intrusive, so that by following a formation into its unweathered portion, recognizable feldspars may often be found. The feldspar method is to be preferred to the heavy residual or "zircon" criterion. The theory upon which the heavy residual method is based is undoubtedly a valid one, yet the studies of a large number of sediments show that any interpretations as to the origin of metamorphic rocks which are based upon its use, cannot be but uncertain. In the examination of marine beach sands from South Carolina and Anticosti Island, crystals of zircon and titanite were found which retained perfectly their crystal outline. Dr. W. H. Twenhofel reports similar results from a study of coral beach sands from the Hawaiian Islands. Such a sediment after conversion to a metamorphic rock would, on the basis of the zircon method, have been interpreted as suggestive of igneous origin. It must be borne in mind, however, that of all the criteria at present available for the determination of the origin of schists and gneisses, the use of field relations, where possible, is by far the most conclusive. Chemical and mineralogical criteria must therefore be subordinated to it. On the basis of practical usefulness and reliability the feldspar criterion should supply a valuable addition to our present laboratory methods.